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EFFECT OF MOISTURE CONTENT ON THE CRITICAL IGNITION ENERGIES OF SOME COMBUSTIBLE MATERIALS

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EFFECT OF MOISTURE CONTENT ON THE CRITICAL IGNITION ENERGIES OF SOME COMBUSTIBLE MATERIALS

By

H. D. BRUCE, Chemist
Forest Products Laboratory[1]

and

W. L. FONS, Physicist
California Forest and Range Experiment Station[2]
Forest Service, U. S. Department of Agriculture

Introduction

The thermal radiation from a nuclear bomb is capable of igniting thin or finely divided combustible materials for a long distance around the center of explosion (1 through 8).[3] Paper, cloth, grasses, broad leaves, pine needles, window shades, and excelsior are examples of kindling fuels that can be so ignited. Materials differ in their ease of ignition by radiation for several reasons (9, 10), one of which is moisture content.

The moisture content of organic materials varies with the temperature and relative humidity of the air. Typical curves showing moisture content and relative humidity conditions for several materials in equilibrium with their surrounding atmosphere are plotted in figure 1 (11, 12). The thinner or more finely divided the material, the more quickly does it reach moisture equilibrium. Since the thin, fine materials are most easily ignited by radiation, it is important to know the effect of moisture on the critical ignition energy, the minimum

[1] Maintained at Madison, Wis., in cooperation with the University of Wisconsin

[2] Maintained at Berkeley, Calif., in cooperation with the University of California.

[3] Underlined numbers in parentheses refer to literature cited at the end of this report.

thermal energy in calories per square centimeter required to ignite a particular material, for a more complete understanding of the phenomenon of ignition by thermal radiation.

The purpose of this report is to bring together and summarize present knowledge and available data on the effect of moisture content on ignition by thermal radiation.

Ignition Testing in the Laboratory

The Laboratory radiation source[4] used by the California Forest and Range Experiment Station and the Forest Products Laboratory consisted essentially of a 12- by 12-inch graphite plate electrically heated within an insulated graphite muffle to about 4,200° F. (2,600° K) (fig. 2) (13, 14). The hot plate was raised from the muffle hydraulically, and its radiation was allowed to fall upon a sample of a test material. The incident energy was varied by varying the distance between specimen and plate.

The test specimen (fig. 3) was usually about 12 by 12 inches in size. The central portion of about 16 square inches received maximum irradiation. The radiant exposure was measured by a calorimeter consisting of two blackened silver disks connected in series to a thermocouple-galvanometer circuit.[5] Two small circular holes were cut in the center of each specimen and through these the two disks were inserted flush with the surface of the test material. The disks absorbed nearly all the radiant energy incident upon them, and their increase in temperature was measured by thermocouple and oscillograph. The temperature change was converted by calculation into calories per square centimeter incident on the disks and adjacent test specimen. The lower half of the specimen was covered with a sheet of asbestos to keep it from burning and obscuring the disks with smoke. The specimen was mounted vertically in a wood frame, which in turn was mounted on an angle-iron support that could be slid back and forth on a horizontal track.

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[4]Originally designed and built by the Engineering Department of the University of California at Los Angeles.

[5]The silver disk heat receivers were 1/2 inch in diameter and approximately 1/8 inch thick, thinly coated on the receiving face with a flat black paint of 96 percent absorptivity for radiant heat. A fine chromel-alumel thermocouple was attached to the back of the disk. To secure sufficient deflection of the recording oscillograph, two disks were used in series.

In "short-pulse" experiments (1), the specimen was held stationary during each exposure to the radiation. The hot plate was raised from the muffle in 0.4 second to a position in front of the specimen, where it paused for about 0.4 second, then was moved up behind a screen in 0.4 second. As the plate moved up behind the screen, an opaque plate dropped in front of the specimen, abruptly cutting off all radiation from the hot plate and warm muffle box. The shape of the short pulse is shown in figure 4. It is roughly equivalent to a square wave of 0.84-second duration.

In "long-pulse" experiments (2), the test specimen was moved on a track toward the hot plate, reaching the nearest point at 3.0 seconds and was then withdrawn the rate of movement being controlled so that the radiant flux upon the specimen approximated closely the shape of the radiation pulse from a thermonuclear source with maximum at 3.0 seconds. The shape of the 3-second pulse is shown in figure 4.

Whether the test material charred, glowed, or flamed during the exposure to radiation was noted. The radiant energy integrated by the heat receivers was recorded in calories per square centimeter. If the specimen was ignited by the radiation, a new specimen of the material was exposed at a greater distance from the hot plate. If the material was only charred, a new specimen was exposed at a lesser distance. This was repeated until the critical ignition energy was known to within ± 0.5 calorie per square centimeter. The upper limit attainable with the equipment was about 25 calories per square centimeter, and few attempts were made to measure critical ignition energies of more than 20 calories per square centimeter.

Humidification

All materials were conditioned to a desired moisture content.

Some of the materials[6] reported upon here were tested by the Department of Engineering, University of California at Los Angeles (UCLA), where they were dried to a low moisture content in an oven at 125° F. for various lengths of time, or conditioned to a higher moisture content in a humidifying cabinet in which air circulated over a pan of salt solution. Such humidification was always followed by storage in an airtight container to diffuse the moisture uniformly through the material. Other materials[6] reported upon were tested at the Forest Products Laboratory (FPL), where the materials were brought to various moisture content levels by drying them in an oven at 200° F. or conditioning them in rooms maintained at 80° F. and at 30, 50, 65, 80, 90, or 97 percent relative humidity.

[6] The forest fuels were tested at UCLA, the fabrics, papers, and cotton mops at Forest Products Laboratory, along with ponderosa pine needles with the long pulse.

At both laboratories, a sample of material was taken just before each exposure and sealed in a glass weighing bottle. The moisture content of this sample was determined by drying it in an oven at 220° F. and expressed as a percentage of the dry weight.

Ignition Testing in the Field

Specimens of materials were exposed to thermal radiation from several nuclear bomb tests in southern Nevada. For exposure, the specimens were mounted in wood box frames 24 by 24 inches square and about 3-1/2 inches deep, covered with chicken wire of 2-inch mesh. The frames were held in place by steel angle-iron stakes driven into the ground at an angle that would orient the specimens toward ground zero and normal to the direction of the incident radiation from the fireball (fig. 5). Specimens were set out in several rows 1,000 feet apart to bracket the expected critical point between ignition and nonignition. The moisture content of the specimens was estimated from the temperature and relative humidity prevailing at the time of each shot, using appropriate equilibrium data.

Specimens were also exposed to thermal radiation from a nuclear weapon explosion at Bikini Atoll (8). These specimens were mounted in metal boxes, some airtight and containing a desiccant that kept the moisture content of the specimens low, others with provision for diffusion of the humid ambient air to assure high moisture content in the specimens. The boxes were opened by a signal a few seconds before the detonation so that the specimen faced the expected point of burst (fig. 6). Air temperatures and humidities were recorded by hygrothermograph. Moisture content values were later determined in the laboratory for samples of the test materials in equilibrium with air at the humidity and temperature conditions prevailing in the vicinity of the specimens at Bikini at shot time.

Materials Tested

The effect of moisture content on ignition by thermal radiation was studied in the laboratory with the materials given in table 1.

Table 1.--Materials ignition-tested at various levels of moisture content

Material	Thickness	Specific gravity (ovendry)
	Cm.	Gr. per cc.
Newspaper, crumpled	0.013	0.41
Black cotton cloth	.020	.42
Blue broadcloth, 4-ounce	.028	.39
Blue denim, 8-ounce	.142	.22
Gray duck, 7-ounce	.074	.42
Gray duck, 12-ounce	.081	.48
Cotton string mops	.153	.09
Ponderosa pine needles	.038	.51
Desert Stipa	.007	.53
Sedge grass	.017	.51
Cheat grass	.003	.37
Beech leaves	.009	.39
Douglas-fir litter	.030 to .10	.32
Hardwood litter	.01 to .10	.36
Sugar pine needles	.029	.54
Brown lichen	.002	.65
Madrone leaves	.028	.45
Punky wood		
White fir (sapwood)		.10
Douglas-fir		.25
White fir (heartwood)		.25
Black oak punk		.10
Wheat straw	.037	.35
Rhododendron leaves	.025	.50
Redwood needles	.046	.42
Black alpha-cellulose paper[1]	.0099 to .077	.55
Black alpha-cellulose paper[2]	.0053 to .080	.75

[1] 3.9 to 30.3 mils.

[2] 2.1 to 31.5 mils.

Test Results

Laboratory Tests with Short Pulse

The laboratory test results with the short pulse on some materials exposed at more than one moisture content are shown in figures 7 and 8.

When the critical ignition energy (Q_c) is plotted against the moisture content (M) of the material, a straight line results,

$$Q_c = a + bM$$

in which a and b are constant for a particular material. Values of a and b for various materials tested by the short pulse are presented in table 2.

Table 2.--Values of constants a and b in equation $Q_c = a + bM$ for short pulse

Material	a	b
Newspaper, crumpled	4.1	0.063
Black cotton cloth, 3-ounce	3.9	.03
Blue cotton broadcloth, 4-ounce	5.9	.07
Blue cotton denim	8.3	.36
Gray cotton duck, 7-ounce	8.7	.32
Gray cotton duck, 12-ounce	11.4	.56
Cotton string mops	7.3	.45
Ponderosa pine needles	5.2	.54
Desert stipa	4.2	.12
Sedge grass	5.0	.10
Cheat grass	4.6	.10
Beech leaves	3.2	.08
Douglas-fir litter	4.5	.10
Sugar pine needles	7.2	.40
Brown lichen	4.2	.10
Madrone leaves	4.2	.38
Punky logs	4.4	.11
Wheat straw	5.8	.14
Rhododendron leaves	5.5	.35
Redwood needles	4.7	.33
Hardwood litter	3.0	.08

Laboratory Tests with Long Pulse

The Laboratory test results with the long pulse (t_{max} = 3.0 sec.) on two materials that were at several levels of moisture content when exposed are shown in figure 9. The Q_c-M equations for the test results are:

Ponderosa pine needles	$Q_c = 14.0 + 0.23\ M$
Crumpled newspaper	$Q_c = 8.0 + 0.08\ M$

Field Tests

Some of the materials studied in the laboratory were also tested by exposure to nuclear bomb radiation in the field. The data from the field tests are given in table 3.

The critical ignition energies drawn from the data of table 3 for the black alpha-cellulose paper are plotted against moisture content in figure 10. The Q_c-M equations for the black alpha-cellulose paper vary with the thickness of the paper and its specific gravity as follows:

Thickness (Mils)	Specific gravity	Equation
2	0.55	$Q_c = 3.2 + 0.05M$
8	.55	$Q_c = 8.2 + 0.17M$
20	.55	$Q_c = 15.6 + 0.34M$
2	.75	$Q_c = 5.3 + 0.03M$
8	.75	$Q_c = 13.8 + 0.11M$
20	.75	$Q_c = 26.2 + 0.25M$

Conclusions

The following conclusions can be drawn from the references and data presented in this report:

1. The equilibrium moisture content (EMC) of a hygroscopic organic material, such as wood, paper, cloth, or grasses, increases with the relative humidity (RH), and the EMC-RH relation is characteristic for each material.

2. The greater the moisture content (M) the greater the minimum radiant energy (Q_c) required to ignite a material.

3. The Q_c -M relation is linear.

4. The thinner the material, the less the effect moisture content has on the critical ignition energy.

5. Total energy required for ignition is greater for a long pulse than for a short pulse, for a material at a given moisture content.

6. The effect of moisture content on the critical ignition energy of black alpha-cellulose paper is less as the specific gravity of the paper increases.

Table 3. --Effects of thermal energy in field tests on combustible materials at different moisture contents

Test material	Shot	Pulse[1] t_{max}	Incident energy	Moisture content	Thermal effect
		Second	Cal/cm^2	Percent	
Crumpled newspaper	U/K-9	0.170	4.3	3.0	Burned
	U/K-4	.110	4.0	3.5	Burned
	U/K-4	.110	3.4	3.5	Slight char
	U/K-9	.170	3.1	3.0	Slight char
Ponderosa pine needles	B/Easy	.185	14.5	6.4	Burned
	T/S-4	.145	10.8	8.9	Burned
	T/S-3	.180	8.8	6.4	Burned
	T/S-[illegible]	.145	8.4	8.9	Charred
	U/K-9	.165	7.7	5.5	Burned
	T/S-3	.180	7.3	6.4	Charred
	U/K-9	.165	6.3	5.5	Charred
	U/K-4	.110	5.4	6.0	None
Ponderosa pine needles	Redwing-Cherokee	2.00	18.2		Burned
		2.00	12.2		Slight char
		2.00	12.1		Charred
		2.00	8.8		None
		2.00	18.2		Burned
		2.00	12.2		Slight char
		2.00	12.1		None
		2.00	8.8		None

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Table 3. --Effects of thermal energy in field tests on combustible materials at different moisture contents (continued)

Test material	Shot	Pulse[1] t_{max}	Incident energy	Moisture content	Thermal effect
		Second	Cal/cm^2	Percent	
Douglas-fir litter	T/S-3	.180	6.0	7.0	Burned
		.180	5.2	7.0	Charred
		.180	5.2	7.0	Charred
		.180	4.6	7.0	Burned
Desert stipa grass	B/Easy	.185	5.3	6.4	Burned
	B/Dog	.152	4.9	9.4	Burned
Sedge grass	B/Charlie	.122	8.5	19.0	Exting. by blast
	B/Baker	.066	7.3	12.8	Exting. by blast
	B/Dog	.152	7.1	9.5	Exting. by blast
	B/Easy	.185	6.2	6.5	Burned
	B/Charlie	.122	5.2	19.0	None
	B/Baker	.066	4.8	12.8	Slight char
	B/Easy	.185	4.5	6.5	None
	B/Dog	.152	4.0	9.5	None
Cheat grass	T/S-4	.145	6.6	9.0	Burned
	T/S-4	.145	5.3	9.0	Charred
	T/S-3	.130	4.6	7.0	Burned
	T/S-4	.145	3.6	9.0	None
	T/S-3	.180	3.5	7.0	None
Beech leaves	T/S-4	.145	5.3	13.9	Burned
	T/S-3	.180	4.6	11.4	Charred
	T/S-4	.145	4.3	13.9	Charred
	T/S-3	.180	3.5	11.4	Burned
Brown lichen	T/S-4	.145	5.3	8.9	Burned
	T/S-3	.180	5.2	6.7	Exting. by blast
	T/S-3	.180	4.6	6.7	Charred
	T/S-4	.145	4.3	8.9	Charred

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Table 3.--Effects of thermal energy in field tests on combustible materials at different moisture contents (continued)

Test material	Shot	Pulse[1] t_{max}	Incident energy	Moisture content	Thermal effect
		Second	Cal/cm^2	Percent	
Madrone leaves	B/Easy	.185	14.5	11.0	Burned
	T/S-4	.145	10.8	13.8	Burned
	B/Easy	.185	10.0	11.0	Burned
	T/S-3	.180	8.8	11.5	Charred
	T/S-4	.145	8.4	13.8	Charred
	T/S-3	.180	7.3	11.5	Burned
	T/S-4	.145	6.6	13.8	Burned
	T/S-3	.180	6.0	11.5	Charred
	T/S-4	.145	5.3	13.8	None
	T/S-3	.180	5.2	11.5	Charred
	T/S-3	.180	4.6	11.5	None
Wheat straw	T/S-3	.180	8.8	6.9	Charred
	T/S-4	.145	8.4	8.8	Exting. by blast
	T/S-3	.180	7.3	6.9	Charred
	B/Easy	.185	6.2	6.4	Burned
	T/S-3	.180	6.0	6.9	Charred
	T/S-4	.145	5.3	8.8	Charred
	T/S-3	.180	5.2	6.9	None
Rhododendron leaves	T/S-4	.145	21.0	13.8	Exting. by blast
	T/S-3	.180	11.0	11.5	Exting. by blast
	T/S-3	.180	8.8	11.5	Charred
	T/S-4	.145	8.4	13.8	Charred
Blue cotton denim	Redwing-	2.00	18.2		Charred
	Cherokee	2.00	12.2		Sl. char
		2.00	12.1		None
		2.00	8.8		None
		2.00	18.2		Charred
		2.00	12.2		None
		2.00	12.1		None
		2.00	8.8		None

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Table 3. --Effects of thermal energy in field tests on combustible materials at different moisture contents (continued)

Test material	Shot	Pulse[1] t_{max}	Incident energy	Moisture content	Thermal effect
		Second	Cal/cm^2	Percent	
Newspaper	Redwing--	2.00	12.1		Burned
	Cherokee	2.00	8.8		Sl. char
		2.00	8.1		Sl. char
		2.00	6.7		None
		2.00	5.9		Sl. char
		2.00	18.2		Very charred
		2.00	12.2		Charred
		2.00	12.1		Sl. char
		2.00	8.8		Sl. char
		2.00	8.1		None
Corrugated fiberboard	Redwing--	2.00	12.1		Charred
	Cherokee	2.00	5.9		None
		2.00	8.8		None
		2.00	8.1		None
Fescue grass	....do...	2.00	12.1		Sl. char
		2.00	8.8		None
		2.00	8.1		None
		2.00	12.1		Sl. char
		2.00	8.8		None
		2.00	8.1		None
Black paper 3.9 mil d = 0.55	....do...	2.00	18.2	1.6	Burned
		2.00	12.1	1.6	Burned
		2.00	8.8	1.6	Burned
		2.00	6.7	1.6	Burned
		2.00	18.2	23.1-24.3	Burned
		2.00	12.1	23.1-24.3	Burned
		2.00	8.8	23.1-24.3	Burned
		2.00	6.7	23.1-24.3	Burned

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Table 3. --Effects of thermal energy infield tests on combustible materials at different moisture contents (continued)

Test material	Shot	Pulse[1]: t_{max}	Incident energy	Moisture content	Thermal effect
		Second	Cal/cm^2	Percent	
Black paper 5.9 mil d = 0.55	Redwing-Cherokee	2.00	18.2	1.6	Burned
		2.00	12.1	1.6	Burned
		2.00	8.8	1.6	Burned
		2.00	6.7	1.6	Burned
		2.00	18.2	23.1-24.3	Burned
		2.00	12.1	23.1-24.3	Burned
		2.00	8.8	23.1-24.3	Burned
		2.00	6.7	23.1-24.3	Burned
Black paper 8.0 mil d = 0.55	....do....	2.00	18.2	1.6	Burned
		2.00	12.1	1.6	Burned
		2.00	8.8	1.6	Burned
		2.00	6.7	1.6	Charred
		2.00	18.2	23.1-24.3	Burned
		2.00	12.1	23.1-24.3	Burned
		2.00	8.8	23.1-24.3	Very charred
		2.00	6.7	23.1-24.3	Very charred
Black paper 9.7 mil d = 0.55	....do....	2.00	18.2	1.6	Burned
		2.00	12.1	1.6	Burned
		2.00	8.8	1.6	Burned
		2.00	6.7	1.6	Very charred
		2.00	18.2	23.1-24.3	Burned
		2.00	12.1	23.1-24.3	Very charred
		2.00	8.8	23.1-24.3	Charred
		2.00	6.7	23.1-24.3	Charred
Black paper 11.6 mil d = 0.55	....do....	2.00	18.2	1.6	Burned
		2.00	12.1	1.6	Burned
		2.00	8.8	1.6	Slight char
		2.00	6.7	1.6	None
		2.00	18.2	23.1-24.3	Burned
		2.00	12.1	23.1-24.3	Very charred
		2.00	8.8	23.1-24.3	None
		2.00	6.7	23.1-24.3	None

Table 3.--Effect of thermal energy in field tests on combustible materials at different moisture contents (continued)

Test material	Shot	Pulse[1] t_{max}	Incident energy	Moisture content	Thermal effect
		Second	Cal/cm^2	Percent	
Black paper 20.2 mil	Redwing--	2.00	18.2	1.6	Burned
d = 0.55	Cherokee	2.00	12.1	1.6	Charred
		2.00	8.8	1.6	None
		2.00	6.7	1.6	None
		2.00	18.2	23.1-24.3	Very charred
		2.00	12.1	23.1-24.3	Charred
		2.00	8.8	23.1-24.3	None
		2.00	6.7	23.1-24.3	None
Black paper 30.3 mil	....do...	2.00	18.2	1.6	Burned
d = 0.55		2.00	12.1	1.6	Charred
		2.00	8.8	1.6	None
		2.00	6.7	1.6	None
		2.00	18.2	23.1-24.3	Charred
		2.00	12.1	23.1-24.3	Slight char
		2.00	8.8	23.1-24.3	None
		2.00	6.7	23.1-24.3	None
Black paper 2.1 mil	....do...	2.00	18.2	1.6	Burned
d = 0.75		2.00	12.1	1.6	Burned
		2.00	8.8	1.6	Burned
		2.00	6.7	1.6	Burned
		2.00	18.2	23.1-24.3	Burned
		2.00	12.1	23.1-24.3	Burned
		2.00	8.8	23.1-24.3	Burned
		2.00	6.7	23.1-24.3	Burned
Black paper 4.1 mil	....do...	2.00	18.2	1.6	Burned
d = 0.75		2.00	12.1	1.6	Burned
		2.00	8.8	1.6	Burned
		2.00	6.7	1.6	Charred
		2.00	18.2	23.1-24.3	Burned
		2.00	12.1	23.1-24.3	Burned
		2.00	8.8	23.1-24.3	Charred
		2.00	6.7	23.1-24.3	Very charred

Table 3. --Effects of thermal energy in field tests on combustible materials at different moisture contents (continued)

Test material	Shot	Pulse[1] t_{max}	Incident energy	Moisture content	Thermal effect
		Second	Cal/cm^2	Percent	
Black paper 6.1 mil d = 0.75	Redwing - Cherokee	2.00	18.2	1.6	Burned
		2.00	12.1	1.6	Burned
		2.00	8.8	1.6	Very charred
		2.00	6.7	1.6	None
		2.00	18.2	23.1-24.3	Burned
		2.00	12.1	23.1-24.3	Burned
		2.00	8.8	23.1-24.3	Charred
		2.00	6.7	23.1-24.3	Charred
Black paper 8.3 mil d = 0.75	....do...	2.00	18.2	1.6	Burned
		2.00	12.1	1.6	Burned
		2.00	8.8	1.6	Very charred
		2.00	6.7	1.6	None
		2.00	18.2	23.1-24.3	Burned
		2.00	12.1	23.1-24.3	Very charred
		2.00	8.8	23.1-24.3	Slight char
		2.00	6.7	23.1-24.3	None
Black paper 10.1 mil d = 0.75	....do...	2.00	18.2	1.6	Burned
		2.00	12.1	1.6	Very charred
		2.00	8.8	1.6	Charred
		2.00	6.7	1.6	None
		2.00	18.2	23.1-24.3	Burned
		2.00	12.1	23.1-24.3	Charred
		2.00	8.8	23.1-24.3	None
		2.00	6.7	23.1-24.3	None
Black paper 12.3 mil d = 0.75	....do...	2.00	18.2	1.6	Very charred
		2.00	12.1	1.6	Very charred
		2.00	8.8	1.6	Slight char
		2.00	6.7	1.6	None
		2.00	18.2	23.1-24.3	Very charred
		2.00	12.1	23.1-24.3	Slight char
		2.00	8.8	23.1-24.3	None
		2.00	6.7	23.1-24.3	None

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Table 3. --Effects of thermal energy in field tests on combustible materials at different moisture contents (continued)

Test material	Shot	Pulse[1] t_{max}	Incident energy	Moisture content	Thermal effect
		Second	Cal/cm^2	Percent	
Black paper 20.3 mil	Redwing-	2.00	18.2	1.6	Charred
d = 0.75	Cherokee	2.00	12.1	1.6	Charred
		2.00	18.2	23.1-24.3	Charred
		2.00	12.1	23.1-24.3	None
		2.00	8.8	23.1-24.3	None
Black paper 31.5 mil	....do...	2.00	18.2	23.1-24.3	Charred
d = 0.75		2.00	12.1	23.1-24.3	None

[1]Calculated from weapon yield.

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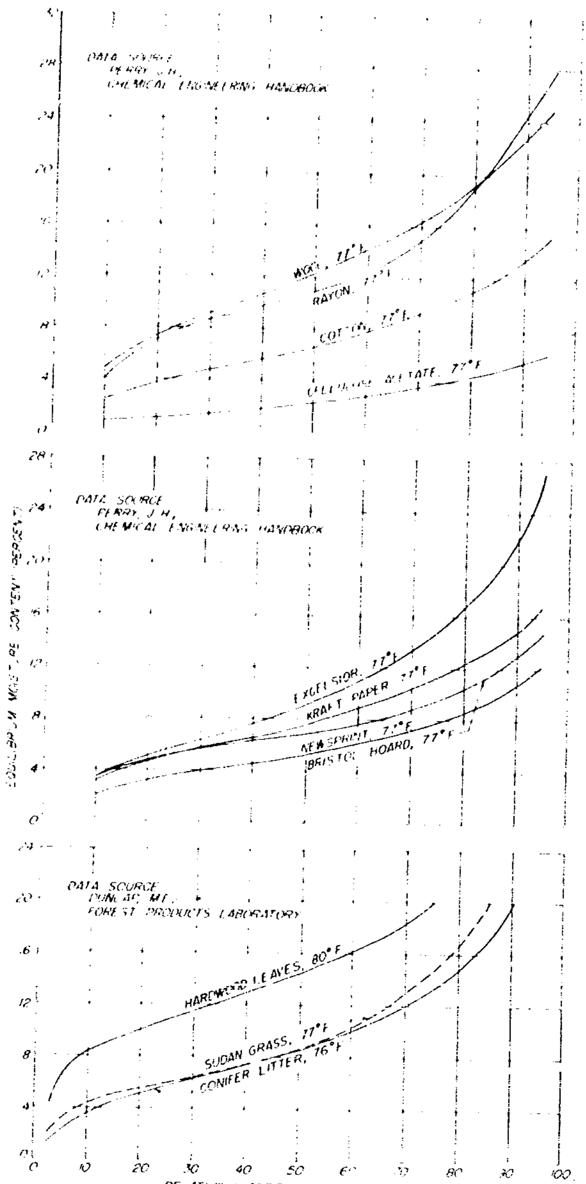

Figure 1. --Equilibrium moisture contents at various relative humidities, for several materials.

Figure 2.--Heated graphite source plate, and muffle

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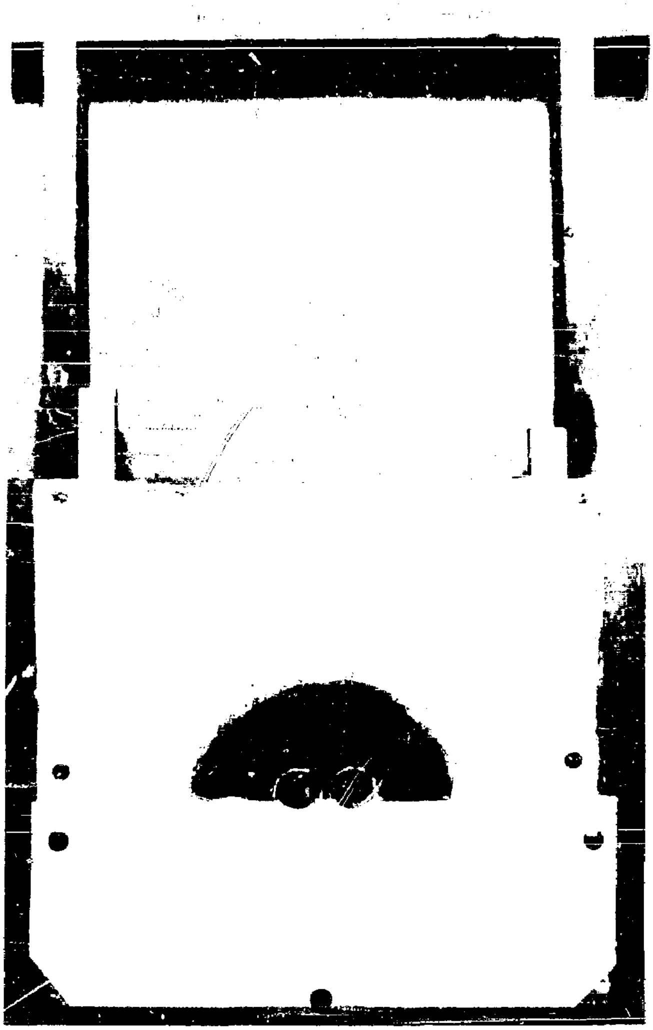

Figure 3. --Typical test specimen charred by radiation from hot plate.

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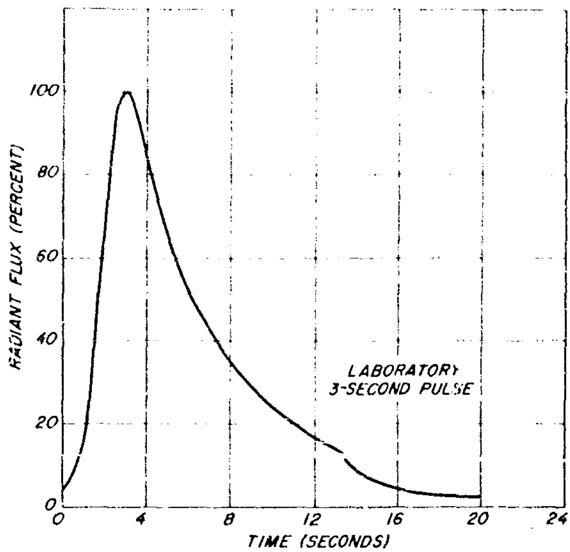

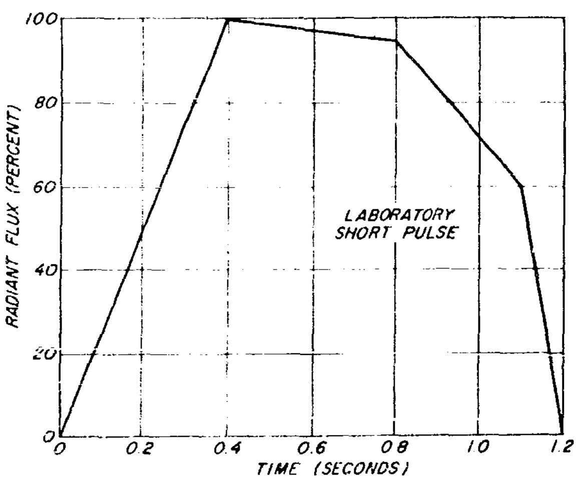

Figure 4. --The long and short radiation pulses employed in studies of the critical ignition energy as related to moisture content.

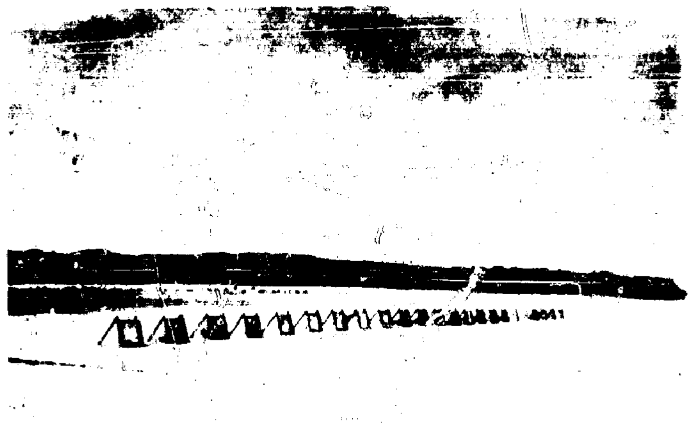

Figure 5.--A row of frames holding combustible test specimens faced towards air zero at a field test in Nevada.

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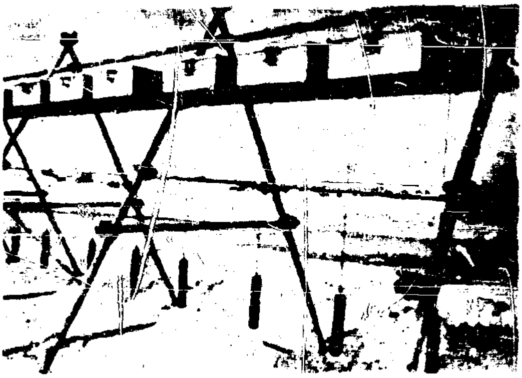

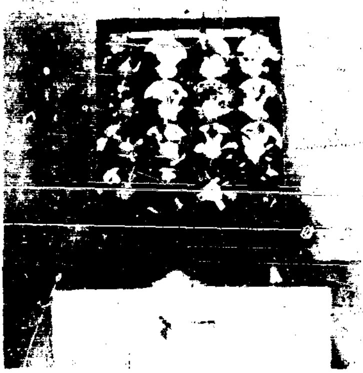

Figure 6.--(Above) Specimen-exposure boxes at Bikini test, ready for opening immediately before detonation.

(Below) Exposure box opened to show the manner in which the test specimens were mounted.

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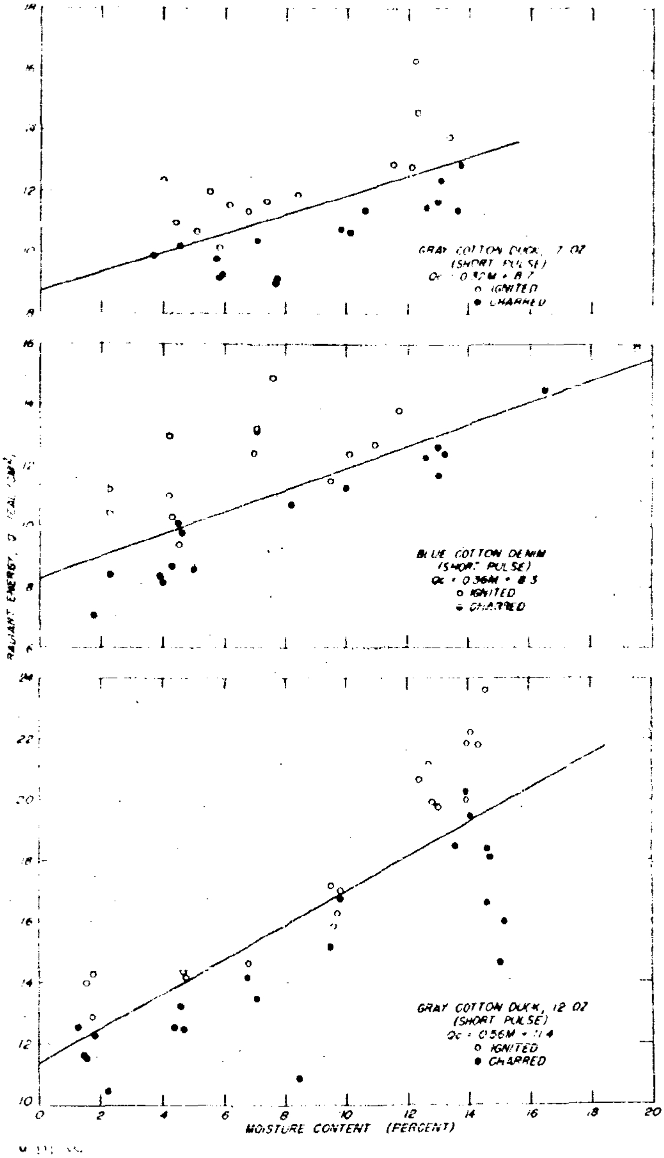

Figure 7. --Effect of short-pulse radiant energy on three combustible materials at various moisture contents (laboratory tests).

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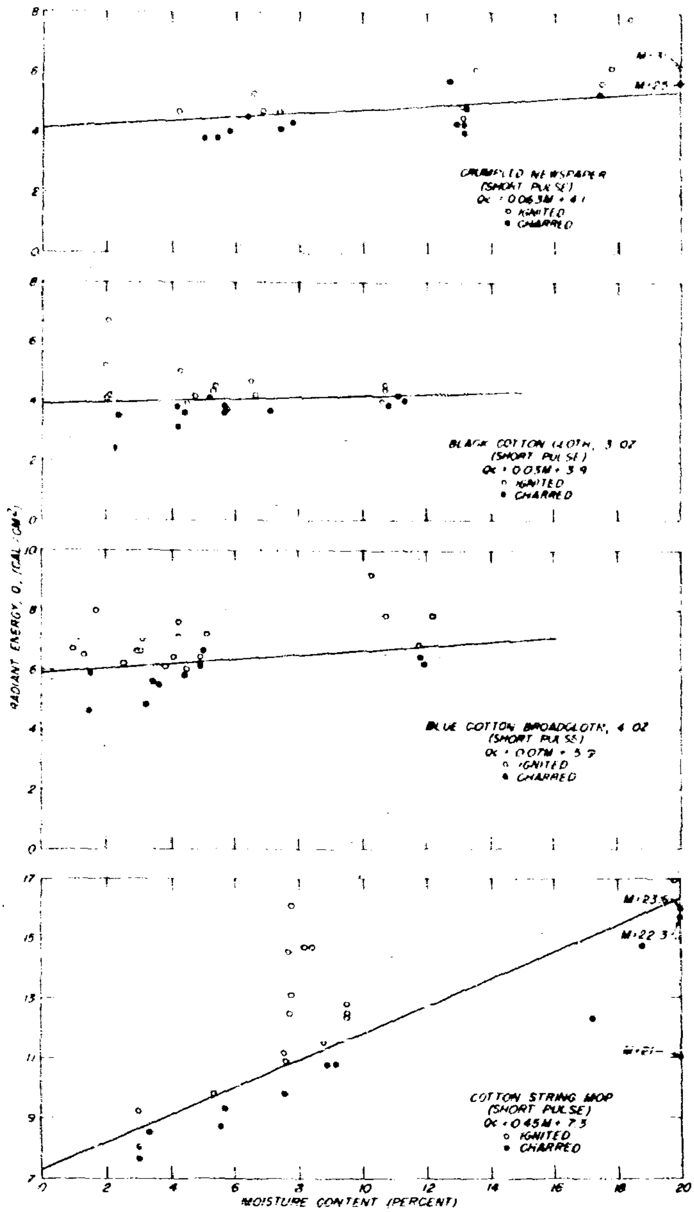

Figure 8. --Effect of short-pulse radiant energy on four combustible materials at various moisture contents (laboratory tests).

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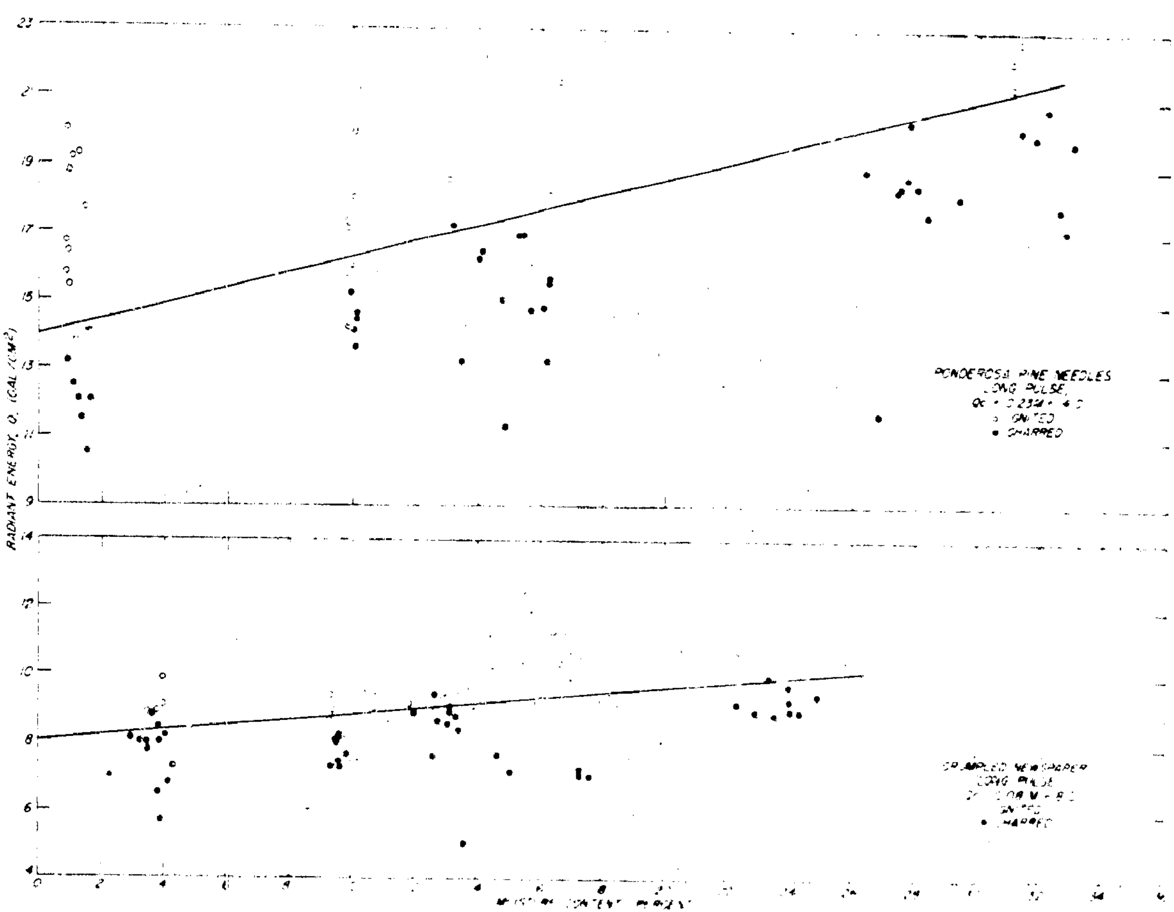

Figure 9. --Effect of long-pulse radiant energy on two combustible materials at various moisture contents (laboratory tests)

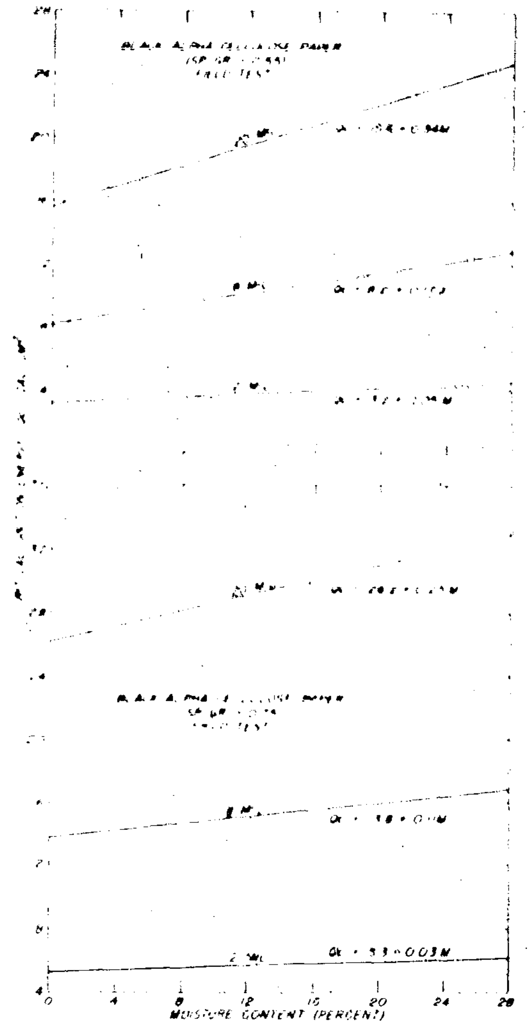

Figure 10. --Effect of moisture content on the critical ignition energy of black alpha-cellulose papers of various thicknesses and specific gravities (field tests)

Defense Threat Reduction Agency

45045 Aviation Drive
Dulles, VA 20166-7517

TRC 3 December 1999

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Ardith Jarrett

ARDITH JARRETT
Chief, Technical Resource Center